# TIME SERIES TEST OF A HARMONIC SERIES MODEL OF ORGANIZATIONAL DIFFERENTIATION

Robert Hamilton Spencer

# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

# THESIS

TIME SERIES TEST OF A HARMONIC SERIES
MODEL OF ORGANIZATIONAL DIFFERENTIATION

BY

Robert Hamilton Spencer, Jr.

March 1975

Thesis Advisor: W. J. Haga

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Time Series Test of a Harmonic Series

Model of Organizational Differentiation

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Data from 68 years in the evolution of an education and training organization was used to test the Mayhew-Childers harmonic series model of role differentiation across time. Previous strategies for testing this model were found to have been inappropriate, and consideration of data collection design was necessary to test any model of role differentiation. The harmonic series model, because of special inherent properties, lent itself to linearity tests of the relationship of transformed variables, which did not support the model as a formal theory. The model did, however, demonstrate predictive properties which led to the proposal of an alternate model. The predictive power of both models increased across time; the alternate model was better in the earlier years while the harmonic series model was better in later years. Suggestion is made for the explicit consideration of time in further studies of role differentiation in formal organizations.

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# I. INTRODUCTION

## A. BACKGROUND

Empirical studies of formal dimensions of organization structure have sought to discover patterns of association between factors that lead to increases in organization complexity [Blau and Schoenerr, (1973); Blauner, (1964); Child, (1973); Hickson, *et al.*, (1969); Samuel and Mannheim, (1970); Woodward, (1965)]. These investigations have attempted to develop a set of hypotheses that are sufficiently generalizable to become the basis for constructing formal theories of organization. Each of these studies has used sample organizations of varying size, purpose, technology, and location to identify causal factors leading to changes in complexity.

Two formal variables that have been examined extensively in the literature are organization size and complexity, or structural differentiation. Causal inferences about size and complexity have been generated largely from cross-sectional research designs. While these designs have been useful in dealing with rival hypotheses and in establishing covariance, cross-sectional designs make arbitrary assumptions about the time ordering of variables. Longitudinal data collection designs are necessary to analyze the causal relationship of organization size to complexity by accounting for the time order of these elements.

In a study of the administrative structures of 194 departments of finance in city, county, and state governments, Meyer [1972] compared survey data collected in 1966 with data collected in a restudy in 1971 of the same organizations. Hendershot and James [1972] used Office of Education data on 299 school districts collected at two points in time. Haire [1959] examined case histories of four organizations in a longitudinal study of growth at five points in time. Moore [1974] examined longitudinal data of one school district spanning seventy years, but with inconclusive results.

## B. LITERATURE ON THE CHARACTERISTICS OF BUREAUCRACIES

### 1. Cross-Sectional Studies of Size and Structural Differentiation

According to Hall [1967], relationships between organization size and other structural components are inconsistent in that neither complexity nor formalization can be predicted from knowledge of organization size. He suggested that size may be irrelevant as a factor in determining structural differentiation.

Klatzky [1970] proposed two models to explain the relationship between the size of an organization and the percentage of its staff personnel. In his regression model, Klatzky's results indicate that the effect of size was partially dependent on the level of complexity in an organization. In his logarithmic model increasing size decreased the staff component at a decreasing rate, explaining slightly more variance than the regression model. However, he rejected the logarithmic model in favor of the regression model. He

reasoned that, although the logarithmic model provided a slightly better fit to his data, it had less theoretical basis than the regression model and, therefore, was unable to explain the social processes involved.

Blau [1970] and Blau and Schoenherr [1971] analyzed the effects of a variety of formal characteristics of structure across 53 employment security agencies, along with parallel analyses of the same characteristics among 387 component divisions and 1201 local offices of these agencies. Their results indicated that size had a positive relationship to differentiation and administrative overhead. Thus, the larger an organization and the scope of its responsibilities, the more pronounced would be its structural differentiation. The same outcome was found among the agencies' subunits. Blau and Schoenherr reasoned, however, that large organizations have a greater structural division of labor; greater size would lead to more structural components. As organizations grew, they generated structural differentiation, and thus, only indirectly raised administrative overhead. On the other hand, the administrative ratio decreased with increases in organizational size despite an increase in the administrative ratio resulting from differentiation in large organizations. They concluded that the relationship between size and other structural variables was nonlinear.

A departure from the Weberian concept of bureaucracy has been pursued by the Aston Group [Pugh, *et al.*, (1968, 1969)]. Their multidimensional approach suggested a need for only four orthogonal dimensions to describe the structure

of any work organization. These have been defined as (a) structuring of activities, which encompasses specialization, standardization, formalization and vertical span; (b) concentration of authority, encompassing centralization, percentage of line managers, and standardization of personnel procedures; (c) line control of work flow; and (d) relative size of supportive component. Pugh and his associates argued that the independence of these first two dimensions implied that Weber's association of structuring with decentralization was no longer useful for describing organizational processes. They further contended [1969] that interactions among independent structural elements allow organizations to bureaucratize along several dimensions.

Child's [1972] replication of the Aston studies confirmed an association between specialization, standardization of procedures, vertical span, and formalization expressed by the structuring of activities concept. However, centralization of decision-making was found to be negatively related to structuring in a way that conformed closely to Weber's [1946] description of the bureaucratic mode of administrative control.

Later, Child [1973] compared size-complexity regressions across different industries using data previously compiled by other investigators in five studies. He found that size, in conjunction with technology, location, and environmental variables, predicted organization complexity. However, the degree of complexity had a more direct relationship with formalization of procedures than it did with size. Further,

complexity was a critical factor in understanding organization structure but was not more significant than size as a determining factor.

Reimann [1973] supported the Aston group's multi-dimensional approach to organization structure. In a factor analysis of data from 19 U.S. manufacturing firms in connection with the structural scales developed by Pugh, *et al.*, [1968] Reimann found three independent dimensions of structure: decentralization, specialization, and formalization. A variety of structural arrangements appeared to be equally viable for the 19 sampled organizations.

Mansfield [1973] reviewed the Aston group's methodology and concluded that the main variables in their research were scalar quantities, not vector quantities, as they had suggested. Mansfield defined vector quantities as those consisting of magnitude and direction. Scalar quantities were composed of magnitude only. Pugh's measures of organizational structure were additive scalar quantities. His tests of whether these measures formed scaleable dimensions was pointless, since showing that they were scaleable dimensions was not necessary to justify the addition of the item scores obtained for these dimensions. Thus, in re-evaluating Pugh's data, the direct relationship between bureaucratization and centralization of decision-making was found to be weak. However, size affected both of these variables. Large bureaucratic organizations were more likely to have decentralized decision-making than small nonbureaucratic ones. Increasing size appeared to compel managers

to govern behavior with rules in order to reduce the range of day to day problems they confronted. Pugh's conclusion that the bureaucratic ideal type was no longer useful may have been premature. Standardization and formalization were found to be associated with other structural variables in a way that was compatible with Weber's reasoning.

2. Longitudinal Studies Involving Size and Structural Differentiation

Haire [1959] used case histories from four industrial firms to support a biological analogy that related size and complexity in the regulation and description of organizational growth. He applied the square-cube law which postulates that, in Euclidean spatial geometry, as volume increases by a cube function, the surface enclosing it increases by only a square. Haire hypothesized that as an organization grows, the internal structure needed to support internal coordination grows faster than overall size, eventually consuming a disporportion of a firm's productive capacity. Thus, disproportionate structural growth across time in these functional areas resulted from survival-oriented resistance to internally generated forces tending to destroy the organization. His results indicated that the percentage of staff increased with size, up to some point, and then stabilized.

Hendershot and James [1972], using data from U.S. school districts at two points in time, found a general negative relationship between size and the administration-production ratio. Additionally, differences in recent histories of growth may confound comparisons of administration

production ratios in organizations of different sizes, as it does for school districts.

In a study using path analytic techniques on city, county, and state departments of finance in 1966 and 1971, Meyer [1972] found the effects of size on number of sub-units, levels of hierarchy, and number of supervisors to be ubiquitous. Causality was unidirectional; other parameters of organizations had almost no effect on size. The effects of size were greatest on parameters which managers could most easily manipulate. Additionally, apparent relationships among parameters other than size vanished when the influence of size was controlled for.

3. <u>The Harmonic Series Model</u>

Mayhew, *et al.*, [1972] drew from Zipf's [1949] general theory of social organization to derive a prediction of the distribution of employees in organization roles, hypothesizing that when other variables affecting structural differentiation are held constant, the expected distribution can be generated with a harmonic series.

4. <u>Summary of the Literature</u>

Predictions from cross-sectional studies about the causal relationship of size and complexity as two dimensions of organization shape have been conflicting. For example, using the Weberian approach, Blau and Schoenherr found that complexity increased at declining rates with increases in size. Yet, another researcher observed that complexity cannot be implied from knowledge of an organization's size

[Hall, (1967)]. Still another postulated that the effect of size is dependent on the level of complexity [Klatzky, (1970)].

Studies by the Aston group, using their multidimensional approach, concluded that organizations may become bureaucratic in a variety of ways. Thus, size and complexity move together, but are subsumed with other variables to determine organization shape. Another study, using cross-sectional data, confirmed the Aston group's finding that size predicted complexity, but concluded that complexity interacts more with formalization than size to predict structure [Child, (1973)]. Mansfield [1973] has suggested that the Aston group interpreted the measurements of their main variables incorrectly. Scalar quantities were discussed as if they were vector quantities, thus limiting the predictive power of the Aston group's multidimensional approach.

Longitudinal studies have also drawn different conclusions from empirical data about the effects of size and complexity on structure. One study concluded that as size increased over time, complexity increased in the form of a disproportion of resources allocated to staff and clerical positions for internal control, coordination, and communication [Haire, (1959)]. Another study suggested a negative relationship between size, growth, and the administration-production ratio [Hendershot and James, (1972)]. Yet another found the effect of size on other structural variables to be pervasive [Meyer, (1972)]. The reason underlying different interpretations of the empirical data may be found in the

different analytic techniques applied to the data, and in the research designs themselves.

The structural determinants of organizations have been treated in the literature primarily at one or two points in time. Size and complexity have not been considered in terms of process. To the extent that size and complexity interact with each other and other structural variables across time, the analysis of data spanning a continuous period of time should refine empirical insights.

## C. OBJECTIVES OF THIS STUDY

This study seeks to examine the harmonic series model developed by Mayhew, *et al.*, [1972]. Time series data was employed to investigate the effects of time upon the size-complexity relationship in the harmonic series form.

## II. METHODOLOGY

### A. THE SAMPLE

The data for this study was gathered from a California Unified School District. The district was established in 1896, and through fiscal year 1945 operated as two school systems, one for elementary grades and the other for a high school. A single Board of School Trustees composed of three elected resident citizens presided over both systems. The Clerk of the Board, one of the elected members, maintained separate financial records and minutes of Board meetings for each of the two districts. Unification of the two districts in fiscal year 1946 resulted in consolidated record keeping. In 1946 the Board membership was also enlarged to five elected residents of the town.

Unified School Districts in California operate under state law, with some financial supervision at the county level, but are basically autonomous in their management. Unified districts differ from other California school districts in that they must contain at least four elementary schools. In addition, at least one high school must be located in the general geographical area of the four elementary schools (California Education Code, 1972).

### B. DESIGN OF DATA COLLECTION

Minutes of the district's Board of School Trustees, dating from fiscal year 1905 through 1962 provided most of

the data on structure for those years. Accompanying financial records for the fiscal years 1905 through 1911 and 1917 through 1922 were also obtained. School district telephone directories listing all school employees by position from fiscal years 1959 through 1974 were used to develop organization charts for these years. Surviving copies of a document entitled "Principal's October Report" were used to refine high school structure and roles, and to cross reference the available financial records on teachers' and administrators' salaries for fiscal years 1915 and 1916, 1918 through 1927, and 1929 through 1974. With the permission of the County Superintendent of Education for Business, annual district reports to the state summarizing Average Daily Attendance, total receipts and expenditures, capital outlay, total teachers' salaries, and total administrators' salaries, were reviewed. These provided further data for fiscal years 1905 through 1974. In addition, these reports listed the number of administrators by category, supervising and non-supervising, and total number of elementary and high school teachers for fiscal years 1905 through 1938.

The high school Principal from fiscal years 1952 through 1972 was contacted to clarify apparent discrepancies in the data for these years. Moreover, the high school Principal from fiscal years 1921 through 1948, through written questions, provided additional structural information for the years spanning his tenure. Three fiscal years, 1956 through 1958, were excluded from the sample because of the lack of reliable information concerning the number of high

school roles in existence and teachers employed during this period.

Data analysis began with construction of an organization chart for each fiscal year. California law requires each school district to dissolve and re-form each July (California Education Code, 1972). The Board of Trustees usually conducted hire-rehire interviews for all school employees during May and June of each year. However, the Board attempted to fill all new or vacated, formally defined, positions whenever the situation arose during the year. Thus, the records of monthly meetings and special meetings of the Board for the 59 available years were used to ascertain necessary modifications to the organization charts. Part-time and full-time positions were differentiated.

A list of all positions was prepared for each year indicating the number of people in each occupation on either a full-time or a part-time basis. Individuals could hold full-time and part-time positions simultaneously, e.g., full-time teacher and part-time librarian. That individual would be counted as one employee in two roles, one full-time and one part-time. By definition, no individual held more than one full-time position. This study is limited to an analysis of full-time positions.

Roles were ranked according to the number of people in each occupation. For example, the role with the largest number of occupants was ranked one, the role with the next largest number of occupants was ranked two, and so on. Ties were ranked in arbitrary sequence. The resulting distribution

constituted the observed rank-frequency distribution of roles for serial ranks. A second distribution of roles, for average ranks, was generated by assigning the mean of adjacent tied ranks as the rank.

## C. ANALYSIS STRATEGY

Mayhew, *et al.*, [1972] have defined the occupational structure of a formal organization mathematically as:

$n$ = the number of different occupational roles in the formal system;

$S$ = the size (number of employees) of the formal system;

$f_i$ = the number (frequency) of employees in the $i^{th}$ occupational role;

$r_i$ = the rank of the $i^{th}$ occupational role according to decreasing values of $f_i$($r_1 = 1$ is the rank of the largest category, $r_2 = 2$ is the rank of the next largest category, etc.);

$p$ = the ratio of the force of unification to the force of diversification, where, under the harmonic series model,

$$p = \frac{\log f_i}{\log n},\ i = 1;\ p = \frac{\log f_1 - \log f_i}{\log r_i}, \qquad (1)$$

$i = 2,3,\ldots,n.$

Thus, under the model,

$$f_i = (n/r_i)^p = f_1 r_i^{-p} \text{ for all } i, \text{ and}$$

$$S = n^p + (n/2)^p + \cdots + (n/n)^p$$
$$= f_1 1^{-p} + f_1 2^{-p} + \ldots + f_1 n^{-p} = f_1 + f_2 + \cdots + f_n.$$

Equation (1) can be rewritten as

$$\log f_i = \log f_1 + (-p)\log r_i, \text{ for all } i, \text{ or}$$

$$\log f_i = a + (-p)\log r_i. \qquad (2)$$

For a given sample, p can be calculated by regressing log f on log r as in (2), and expected values of f can be generated. An appropriate goodness-of-fit test can then be applied to determine how well the harmonic series model fits the sample. Mayhew, *et al.*, [1972] employed the Chi-square goodness-of-fit test in their analysis of the harmonic series model. Their use of the Chi-square statistic was tested with these samples, both for serial ranks and average ranks.

Under the model, equation (2) specifies the relationship between log f and log r to be linear; thus an appropriate test of the linearity of that relationship also tests the appropriateness of the model. A test for linearity between log f and log r was performed on each of the 67 samples, for serial ranks only. Reasons for omitting average ranks in this case are discussed in Chapter IV.

# III. EMPIRICAL FINDINGS

The test for linearity revealed no strong evidence for the harmonic series model as a formal theory of organization role differentiation. Table II shows that acceptance of the null hypothesis that log f and log r are linearly related occurred in only four of the 67 cases.

The Chi-square test of the null hypothesis that the sample of observed frequencies was drawn from the expected distribution appeared to support the harmonic series model. However, this was found to be a premature conclusion. Further discussion of this point appears in Chapter IV. Results of the Chi-square test, for serial and average ranks, are presented in Table I.

Table I. Results of Chi-square test of $H_0$: Observed Frequencies were Sampled from the Expected Distribution (Reject $H_0$ if Generated $\chi^2$ Exceeds Critical $\chi^2$).

| Sample Year | $\chi^2$ Generated by Sample (Serial Ranking) | $\chi^2$ Generated by Sample (Average Ranking) | Critical $\chi^2$ |
|---|---|---|---|
| 1905 | 3.0115 | 0.0 | 9.488 |
| 1906 | 3.0115 | 0.0 | 9.488 |
| 1907 | 3.8235 | 0.0 | 9.488 |
| 1908 | 4.6804 | 0.0 | 9.488 |
| 1909 | 4.6804 | 0.0 | 9.488 |
| 1910 | 3.8235 | 0.0 | 9.488 |
| 1911 | 6.9274 | 0.0 | 14.067 |
| 1912 | 6.0622 | 0.0 | 11.070 |
| 1913 | 5.6545 | 1.5497 | 14.067 |
| 1914 | 4.5670 | 1.1937 | 14.067 |
| 1915 | 5.4583 | 1.3455 | 15.507 |
| 1916 | 4.2799 | 0.9952 | 15.507 |
| 1917 | 4.9702 | 1.0986 | 16.919 |
| 1918 | 5.4583 | 1.3455 | 15.507 |
| 1919 | 5.4583 | 1.3455 | 15.507 |
| 1920 | 6.7774 | 1.7347 | 15.507 |
| 1921 | 5.1669 | 1.8900 | 16.919 |
| 1922 | 9.7544 | 2.6158 | 15.507 |
| 1923 | 16.8200 | 3.8868 | 19.675 |
| 1924 | 20.1673 | 4.3053 | 22.362 |
| 1925 | 26.5719 | 5.7683 | 22.362 |
| 1926 | 26.5719 | 5.7683 | 22.362 |
| 1927 | 27.8573 | 12.4219 | 22.362 |
| 1928 | 12.9259 | 3.2500 | 18.307 |
| 1929 | 17.0928 | 5.9796 | 22.362 |
| 1930 | 21.8096 | 9.2911 | 26.296 |
| 1931 | 25.8720 | 13.5255 | 27.587 |
| 1932 | 28.8193 | 12.0464 | 27.587 |
| 1933 | 35.9769 | 16.0369 | 27.587 |
| 1934 | 28.1232 | 12.1413 | 28.869 |

Table I. Continued

| | | | |
|---|---|---|---|
| 1935 | 22.0282 | 9.2156 | 28.869 |
| 1936 | 20.1239 | 11.2552 | 27.587 |
| 1937 | 19.7920 | 10.9099 | 26.296 |
| 1938 | 13.7331 | 8.6651 | 26.296 |
| 1939 | 12.7534 | 8.0449 | 24.996 |
| 1940 | 14.1004 | 9.0987 | 26.296 |
| 1941 | 15.6000 | 9.1034 | 24.996 |
| 1942 | 11.9857 | 4.3955 | 24.996 |
| 1943 | 17.5507 | 7.8684 | 26.296 |
| 1944 | 15.5581 | 8.3831 | 23.685 |
| 1945 | 15.0198 | 8.7574 | 24.996 |
| 1946 | 37.1476 | 20.6284 | 26.296 |
| 1947 | 35.6871 | 12.6464 | 31.410 |
| 1948 | 40.9006 | 29.7764 | 28.869 |
| 1949 | 37.3331 | 25.3608 | 30.144 |
| 1950 | 45.1816 | 34.2499 | 28.869 |
| 1951 | 17.7850 | 12.5858 | 32.671 |
| 1952 | 27.5735 | 19.7283 | 35.172 |
| 1953 | 60.9151 | 38.5649 | 41.337 |
| 1954 | 22.8529 | 16.6300 | 37.652 |
| 1955 | 36.1874 | 27.2077 | 40.113 |
| 1959 | 11.5473 | 8.4131 | 52.200 |
| 1960 | 21.3824 | 18.9949 | 58.124 |
| 1961 | 14.8027 | 13.5146 | 57.000 |
| 1962 | 13.5571 | 12.2513 | 50.999 |
| 1963 | 13.0080 | 12.1001 | 64.000 |
| 1964 | 13.8940 | 11.1647 | 67.505 |
| 1965 | 15.7592 | 15.5170 | 65.171 |
| 1966 | 16.2346 | 14.1928 | 72.153 |
| 1967 | 19.6738 | 15.9110 | 81.381 |
| 1968 | 19.8718 | 17.3326 | 81.381 |
| 1969 | 25.6615 | 26.4398 | 79.082 |
| 1970 | 29.089 | 28.1906 | 73.300 |
| 1971 | 17.5406 | 18.2903 | 79.082 |
| 1972 | 27.5914 | 24.8833 | 79.082 |

Table I. Continued

| | | | |
|---|---|---|---|
| 1973 | 6.7682 | 6.4879 | 91.680 |
| 1974 | 19.7200 | 12.5139 | 90.531 |

Table II. Value of $t$ Generated in Testing $H_0$: log f is linearly related to log r (Reject $H_0$ if Generated $t$ Greater than Critical $t$)

| Year | Generated $t$ | Critical $t$ |
|---|---|---|
| 1905 | 6.01 | 4.303 |
| 1906 | 6.01 | 4.303 |
| 1907 | 6.01 | 4.303 |
| 1908 | 6.01 | 4.303 |
| 1909 | 6.01 | 4.303 |
| 1910 | 6.01 | 4.303 |
| 1911 | 6.57 | 2.571 |
| 1912 | 6.26 | 3.182 |
| 1913 | 10.33 | 2.447 |
| 1914 | 10.28 | 2.447 |
| 1915 | 10.05 | 2.365 |
| 1916 | 10.02 | 2.365 |
| 1917 | 9.91 | 2.306 |
| 1918 | 10.05 | 2.365 |
| 1919 | 10.05 | 2.365 |
| 1920 | 10.02 | 2.365 |
| 1921 | 6.82 | 2.306 |
| 1922 | 9.79 | 2.365 |
| 1923 | 9.07 | 2.228 |
| 1924 | 10.09 | 2.201 |
| 1925 | 12.33 | 2.201 |
| 1926 | 12.33 | 2.201 |
| 1927 | 6.58 | 2.179 |
| 1928 | 2.49 | 2.262 |
| 1929 | 3.44 | 2.179 |
| 1930 | 5.80 | 2.131 |
| 1931 | 8.96 | 2.120 |
| 1932 | 4.86 | 2.120 |
| 1933 | 6.29 | 2.120 |
| 1934 | 6.55 | 2.110 |
| 1935 | 6.48 | 2.110 |
| 1936 | 6.47 | 2.120 |
| 1937 | 3.60 | 2.131 |
| 1938 | 3.47 | 2.131 |
| 1939 | 3.16 | 2.145 |
| 1940 | 4.39 | 2.131 |
| 1941 | 3.51 | 2.160 |
| 1942 | * | * |
| 1943 | 2.40 | 2.131 |
| 1944 | 5.31 | 2.179 |
| 1945 | 3.96 | 2.160 |
| 1946 | 6.23 | 2.145 |
| 1947 | 7.70 | 2.101 |
| 1948 | 6.18 | 2.120 |
| 1949 | 5.46 | 2.110 |
| 1950 | 6.20 | 2.120 |
| 1951 | 3.28 | 2.093 |

Table II. Continued

| | | |
|---|---|---|
| 1952 | 4.04 | 2.074 |
| 1953 | 9.94 | 2.052 |
| 1954 | 3.21 | 2.069 |
| 1955 | 3.76 | 2.060 |
| 1959 | 3.40 | 2.031 |
| 1960 | 2.98 | 2.021 |
| 1961 | 3.52 | 2.024 |
| 1962 | 3.19 | 2.034 |
| 1963 | 3.43 | 2.015 |
| 1964 | 3.25 | 2.011 |
| 1965 | 4.47 | 2.014 |
| 1966 | 2.48 | 2.007 |
| 1967 | * | * |
| 1968 | * | * |
| 1969 | 3.50 | 2.003 |
| 1970 | 5.19 | 2.008 |
| 1971 | 4.25 | 2.003 |
| 1972 | 5.55 | 2.003 |
| 1973 | 1.80 | 1.997 |
| 1974 | 4.63 | 1.997 |

* No *t* was generated by these samples and therefore the linear relationship was accepted.

# IV. DISCUSSION

## A. TESTS FOR GOODNESS-OF-FIT OF THE HARMONIC SERIES MODEL

As explained in Chapter II, a theoretical distribution was generated for each sample, resulting in 67 cases in which a model was to be tested, using only one sample in each case. Tests for goodness-of-fit were thus restricted to one-sample tests of which only two are found in the literature: the Chi-square test and the Kolmogorov-Smirnov one-sample test.

Moore [1974] applied the Kolmogorov-Smirnov two-sample exact test to the same data used in this study. Since the implicit null hypothesis in the use of any two-sample test is that two samples were randomly drawn from the same unknown distribution, his approach was inappropriate. Additionally, employment of the Kolmogorov-Smirnov test assumes the independent variable to be continuously distributed [Siegel, (1956)]. This was not true in this study -- the independent variable (rank) was highly discrete. Use of the Kolmogorov-Smirnov one-sample test was therefore rejected.

The Chi-square test was also found to be inappropriate in that it requires expected frequencies in each cell to be greater than five. Siegel [1956] and others suggest grouping data to overcome this restriction. This would not have been appropriate, since it is the nature of organizations to structure themselves with a large proportion of roles occupied by fewer than five members.

If this restriction had been overlooked, the erroneous conclusion would have been drawn that the model did indeed fit the data. Also, it appears that use of the Chi-square test in investigating any hypothesized distribution of members among roles would be inappropriate, which leads this writer to suspect the validity of the results obtained by Mayhew, *et al.*, [1972].

The different results obtained by using average and serial ranks also contradicted James's [1974] contention that it makes no difference which ranking scheme is used.

## B. TESTING FOR LINEARITY OF THE RELATIONSHIP OF log f TO log r

### 1. Effects of Average Ranks

In performing the regression of log f on log r, both serial ranks and average ranks were used to generate expected values for the Chi-square tests. The consistently "better fit" achieved through average ranking prompted close inspection of differences between serially-ranked and average-ranked data.

Data from a representative sample as shown in Figure 1. Note that where tied ranks existed, serially-ranked data preserved the uniqueness of each role, while average-ranked data did not. This property may not have affected the least-squares linear fit to untransformed data -- results for serial and average ranks might have been identical. However, when a nonlinear transformation is applied to either or both variables, different results would be expected, as happened in this study. Similarly, different results would

| Observed Frequency | Serial Rank | Average Rank |
|---|---|---|
| 65 (1 observation) | 1 | 1 |
| 15 (1 observation) | 2 | 2 |
| 14 (1 observation) | 3 | 3 |
| 12 (1 observation) | 4 | 4 |
| 10 (2 observations) | 5,6 | 5.5 |
| 9 (1 observation) | 7 | 7 |
| 8 (2 observations) | 8,9 | 8.5 |
| 7 (1 observation) | 10 | 10 |
| 6 (2 observations) | 11,12 | 11.5 |
| 5 (1 observation) | 13 | 13 |
| 4 (4 observations) | 14-17 | 15.5 |
| 3 (7 observations) | 18-24 | 21 |
| 2 (7 observations) | 25-31 | 28 |
| 1 (19 observations) | 32-50 | 41 |

Figure 1. Serially-ranked and average-ranked data of a representative sample (1965).

be expected in fitting any nonlinear model to the original data, as was the case in this study.

Again, from Figure 1, notice that the number of observations for which tied ranks occurred is substantial, and that observed frequencies of three or less constituted over half the sample. In using average ranks, after application of the log transform to each variable, this high concentration of observations in only three distinct data points had the effect of forcing the least-squares linear model very nearly through those points, and created a bias toward linearity. For this reason, the average ranking scheme was not considered in testing the linearity of the log f-log r relationship.

2. The Linearity Test

To test for linearity, a stepwise multiple regression [Bolch and Huang, (1974)] of log f on log r, $(\log r)^2$, and $(\log r)^3$ was performed for each sample, forcing the linear term (log r) to enter first. The most significant of the quadratic and the cubic terms then entered the regression, with the remaining term entering third. Both the second and third terms were required to have an F-ratio higher than 3.0 to enter the regression.

At the end of both the second and third steps, the null hypothesis, that the coefficient of the term which had entered was zero, was tested at the .05 level against the two-sided alternative that the coefficient was different from zero. This was accomplished by comparing the ratio of the coefficient to its standard error to the associated *t*

statistic, rejecting the null hypothesis when the calculated ratio was the larger of the two. As suggested by Miller and Freund [1965], if either coefficient was concluded to be nonzero, it was inferred that the linear term was insufficient to explain the relationship between log f and log r, and thus that the relationship was nonlinear. If neither the quadratic nor the cubic term entered the regression, it was concluded that the linear term was sufficient and that the relationship was linear.

3. Results of the Linearity Tests

While linearity was rejected in 63 of the 67 samples, it was noted that correlation coefficients of log f to log r tended to be greater than 0.95, suggesting that, although the harmonic series model could not be accepted as a formal theory of organizational role differentiation, it did have strong predictive properties. Therefore the residuals of several samples were examined. It was discovered that the residuals themselves behaved in what appeared to be some sort of exponential fashion, suggesting

$$\log(\log f_i) = b - q(\log r_i),$$

or (3)

$$\log f_i = e^b r_i^{-q},$$

where b and q are positive constants, as an alternate model worthy of investigation.

The relationship specified in (3) above can also be expressed as

$$f_i = k(e^{r_i^{-q}}), \text{ where } k = f_1/e,$$

which gives the explicit relationship of f to r under the alternate model.

4. Testing the Alternate Model

Because the harmonic series model had good predictive properties, the alternate model was tested by comparing it with the harmonic series. Log(log f) was regressed on log r and expected values of f were generated. Errors between the expected values and observed values, in log-log form, were calculated for each model as

$$\log(\log f_i) - \log(\log f_i')$$

where $f_i$ denoted the $i^{th}$ observed value and $f_i'$ denoted the $i^{th}$ expected value. These errors were then squared, summed, and averaged over n to obtain adjusted mean square errors for each model for comparisons. The model with the lower adjusted mean square error was inferred to have better predictive properties for the given sample.

Results obtained in calculating the mean square errors are presented in Table III. These results show that the alternate model had consistently better predictive properties prior to 1942, while the harmonic series model had consistently better predictive properties after 1958. In the years 1942 through 1958, neither model could be said to be better than the other. Also shown is a downward trend in the error terms over time for both models, although the trend was more pronounced for the harmonic series model.

Table III. Mean-Square Errors of the Harmonic Series Model vs. Mean-Square Errors of the Alternate Model

| Year | MSE for Harmonic Model | MSE for Alternate Model |
|---|---|---|
| 1905 | 0.107 | 0.056 |
| 1906 | 0.107 | 0.056 |
| 1907 | 0.120 | 0.060 |
| 1908 | 0.134 | 0.064 |
| 1909 | 0.134 | 0.064 |
| 1910 | 0.120 | 0.060 |
| 1911 | 0.097 | 0.056 |
| 1912 | 0.124 | 0.064 |
| 1913 | 0.087 | 0.036 |
| 1914 | 0.079 | 0.034 |
| 1915 | 0.077 | 0.035 |
| 1916 | 0.070 | 0.033 |
| 1917 | 0.068 | 0.034 |
| 1918 | 0.077 | 0.035 |
| 1919 | 0.077 | 0.035 |
| 1920 | 0.084 | 0.038 |
| 1921 | 0.060 | 0.025 |
| 1922 | 0.097 | 0.041 |
| 1923 | 0.091 | 0.044 |
| 1924 | 0.084 | 0.043 |
| 1925 | 0.092 | 0.045 |
| 1926 | 0.092 | 0.045 |
| 1927 | 0.076 | 0.029 |
| 1928 | 0.039 | 0.024 |
| 1929 | 0.044 | 0.023 |
| 1930 | 0.055 | 0.024 |
| 1931 | 0.062 | 0.023 |
| 1932 | 0.051 | 0.024 |
| 1933 | 0.062 | 0.027 |
| 1934 | 0.057 | 0.025 |
| 1935 | 0.053 | 0.024 |
| 1936 | 0.049 | 0.019 |
| 1937 | 0.034 | 0.019 |
| 1938 | 0.026 | 0.016 |
| 1939 | 0.024 | 0.016 |
| 1940 | 0.032 | 0.015 |
| 1941 | 0.022 | 0.021 |
| 1942 | 0.023 | 0.028 |
| 1943 | 0.027 | 0.023 |
| 1944 | 0.026 | 0.026 |
| 1945 | 0.024 | 0.022 |
| 1946 | 0.030 | 0.028 |
| 1947 | 0.031 | 0.031 |
| 1948 | 0.023 | 0.026 |
| 1949 | 0.023 | 0.024 |
| 1950 | 0.023 | 0.026 |

Table III. Continued

| | | |
|---|---|---|
| 1951 | 0.016 | 0.019 |
| 1952 | 0.021 | 0.015 |
| 1953 | 0.056 | 0.017 |
| 1954 | 0.016 | 0.019 |
| 1955 | 0.018 | 0.017 |
| 1959 | 0.016 | 0.031 |
| 1960 | 0.018 | 0.033 |
| 1961 | 0.019 | 0.038 |
| 1962 | 0.017 | 0.035 |
| 1963 | 0.016 | 0.034 |
| 1964 | 0.015 | 0.032 |
| 1965 | 0.020 | 0.041 |
| 1966 | 0.018 | 0.033 |
| 1967 | 0.020 | 0.029 |
| 1968 | 0.026 | 0.033 |
| 1969 | 0.026 | 0.043 |
| 1970 | 0.025 | 0.047 |
| 1971 | 0.021 | 0.038 |
| 1972 | 0.027 | 0.048 |
| 1973 | 0.019 | 0.029 |
| 1974 | 0.022 | 0.040 |

# V. CONCLUSIONS

## A. GOODNESS-OF-FIT TESTS AND ROLE DIFFERENTIATION

Because it is the nature of organizations to structure themselves with a large proportion of roles occupied by fewer than five members, the Chi-square test was found to be inappropriate in testing goodness-of-fit of role differentiation data to any hypothesized model. Assumptions of other one-sample tests were also violated, pointing to the need for two or more samples of equal sizes (in terms of number of roles) in testing any model which is defined in part by organization size. Further investigation of this point is desirable, as it would help determine appropriate criteria for future data designs.

## B. TIME-SERIES DATA AND THE HARMONIC SERIES MODEL

While the harmonic series model was rejected as a formal theory of organizational role differentiation, its usefulness as a predictor was found to increase across time. The alternate model also showed improvement over time with respect to predictive power. These findings suggest a relationship between time and organizational structure and demonstrate the need for consideration of time as an independent variable in studies of organizational role differentiation.

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